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(54) **METHODOLOGY FOR GENERATING HIGH FIDELITY DIGITAL ZOOM FOR MOBILE PHONE CAMERAS**

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G06K 9/46	(2006.01)
G06T 3/00	(2006.01)
G06T 3/60	(2006.01)
H04N 5/265	(2006.01)
G06T 5/50	(2006.01)
G06T 7/20	(2006.01)
G06T 3/40	(2006.01)

(52) **U.S. Cl.**

CPC ***H04N 5/23296*** (2013.01); ***G06K 9/46*** (2013.01); ***G06T 3/0006*** (2013.01); ***G06T 3/4007*** (2013.01); ***G06T 3/60*** (2013.01); ***G06T 5/50*** (2013.01); ***G06T 7/20*** (2013.01); ***H04N 5/23232*** (2013.01); ***H04N 5/265*** (2013.01); *G06T 2200/12* (2013.01); *G06T 2207/20024* (2013.01); *G06T 2207/20182* (2013.01); *G06T 2207/20212* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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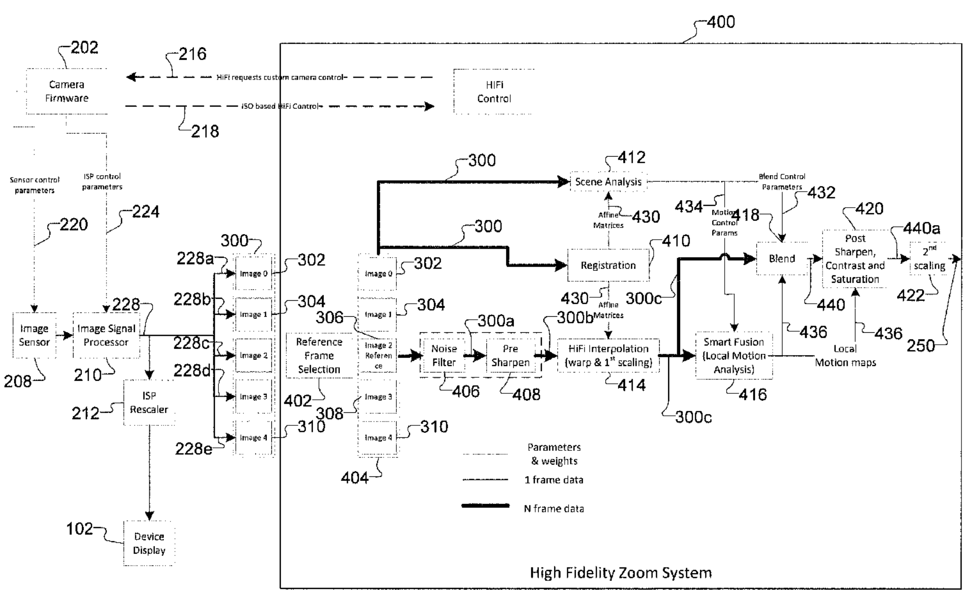
(57) **ABSTRACT**

A mobile device includes an embedded digital camera that is configured to capture a burst of N images. The mobile device includes processing circuitry comprising a registration module configured to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image. The processing circuitry includes a High Fidelity Interpolation block configured to, for each image within the burst of images: perform affine transformation using the set of affine matrices associated with the image, apply an aliasing-retaining interpolation filter, and implement rotation transformation and sub-pixel shifts, yielding an interpolated image. The processing circuitry includes a blending module configured to receive the N interpolated images and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

20 Claims, 5 Drawing Sheets



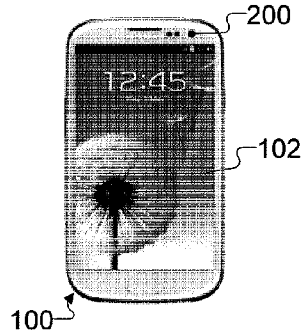


FIGURE 1

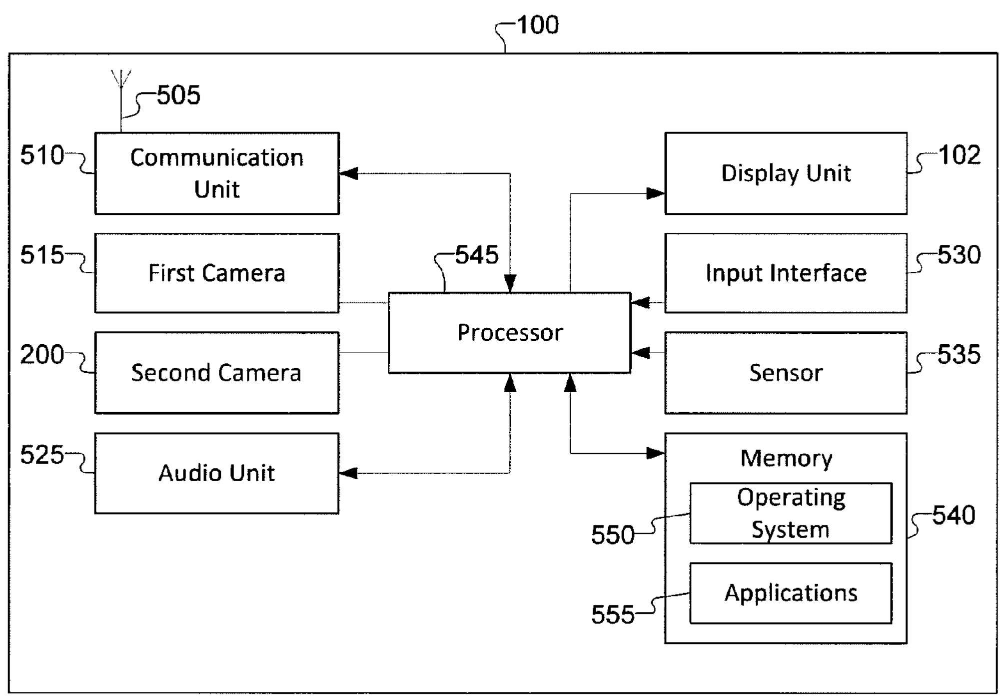


FIGURE 5

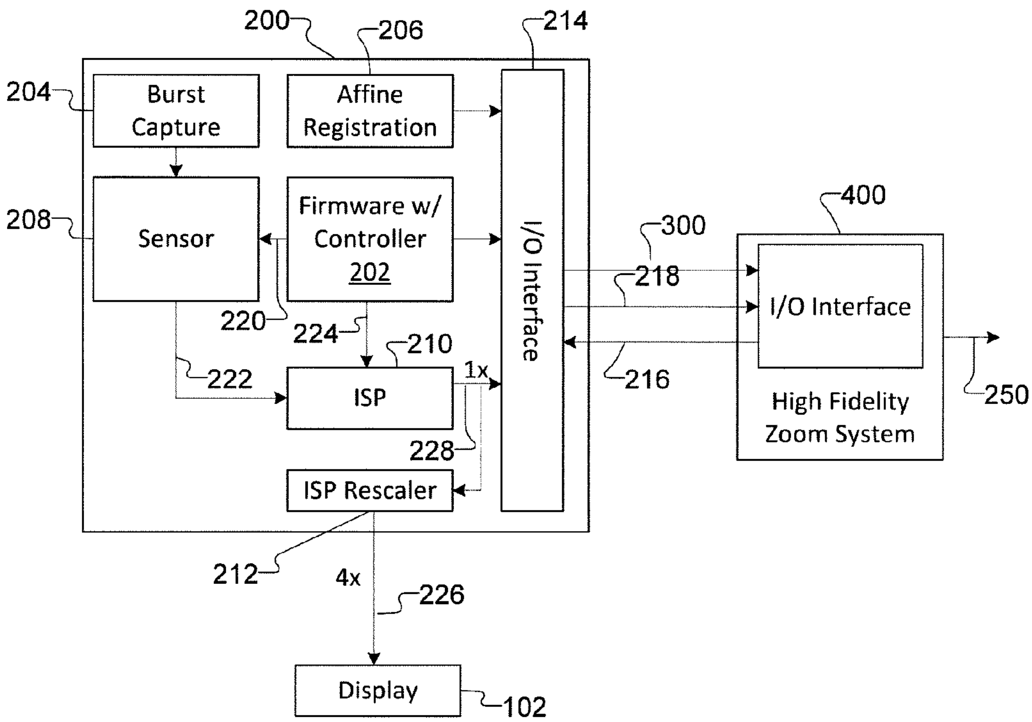


FIGURE 2

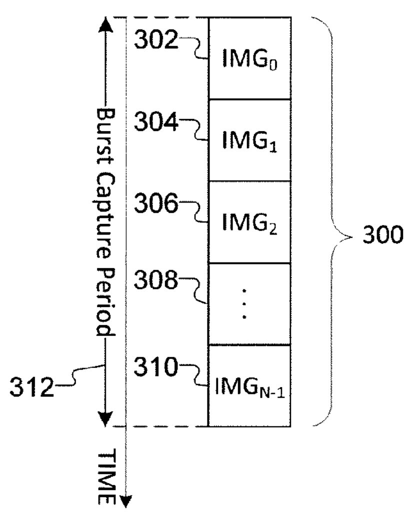


FIGURE 3

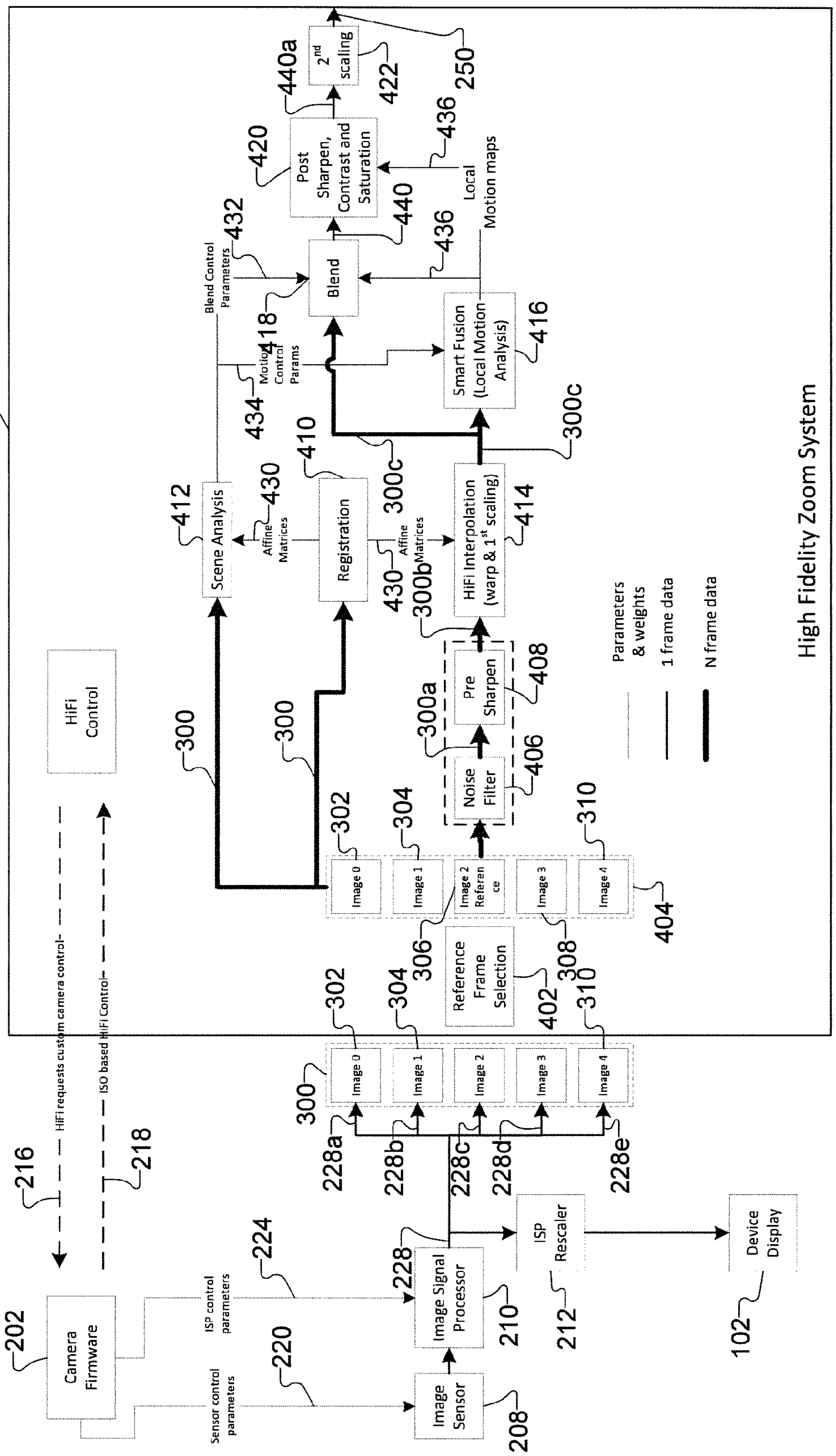

400
HiFi Control
HiFi requests custom camera control
ISO based HiFi Control
216
218
Camera Firmware
202
Sensor control parameters
220
ISP control parameters
224
Image Sensor
208
Image Signal Processor
210
228
ISP Rescaler
212
Device Display
102
228a
228b
228c
228d
228e
300
Image 0
Image 1
Image 2
Image 3
Image 4
302
304
310
Reference Frame Selection
402
306
308
Image 2 Reference
404
Noise Filter
406
Pre Sharpen
408
300a
HiFi Interpolation (warp & 1st scaling)
414
300b
Registration
410
Affine Matrices
430
Scene Analysis
412
300c
Smart Fusion (Local Motion Analysis)
416
Motion Control Params
434
Blend Control Parameters
432
Blend
418
436
Local Motion maps
Post Sharpen, Contrast and Saturation
420
440
2nd scaling
422
440a
250
Parameters & weights
1 frame data
N frame data
High Fidelity Zoom System

FIGURE 4

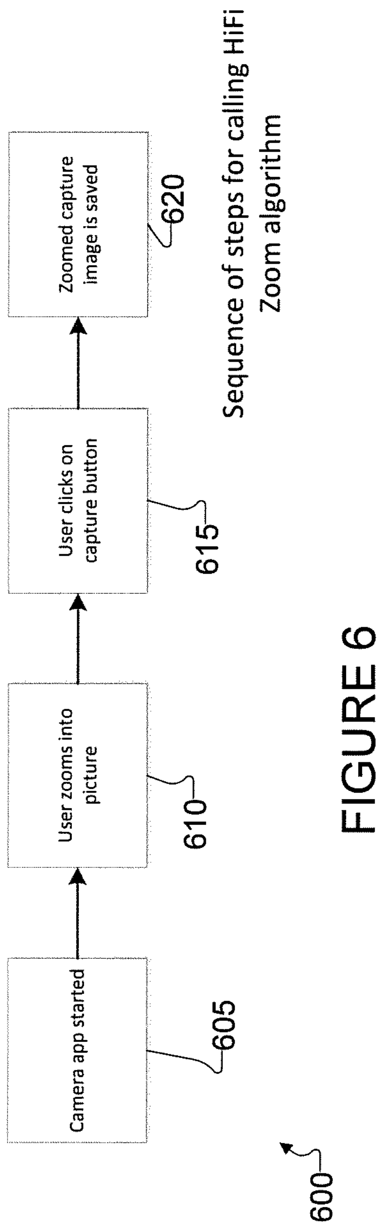


FIGURE 6

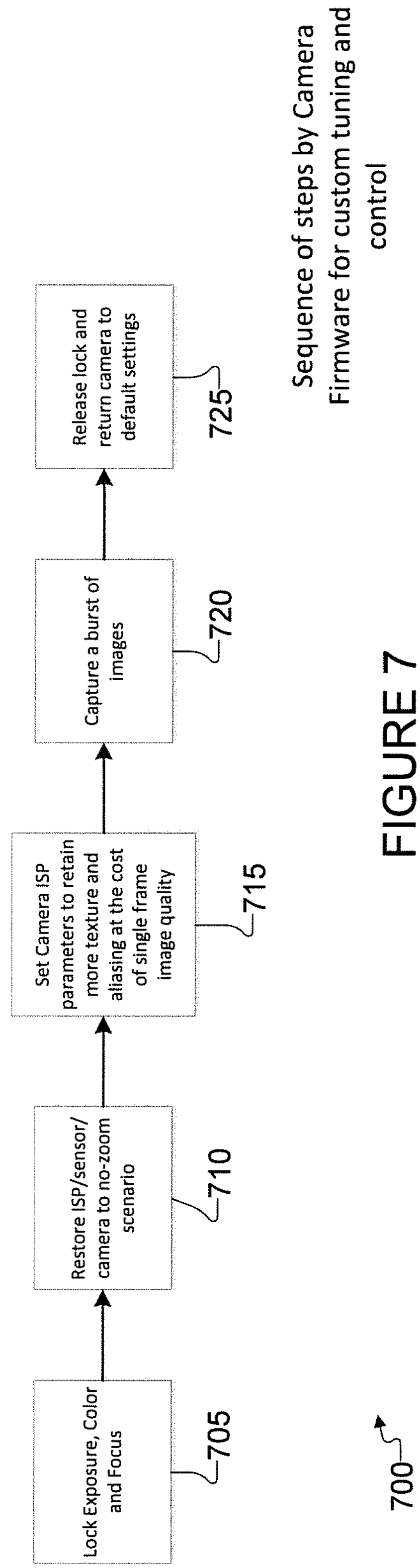


FIGURE 7

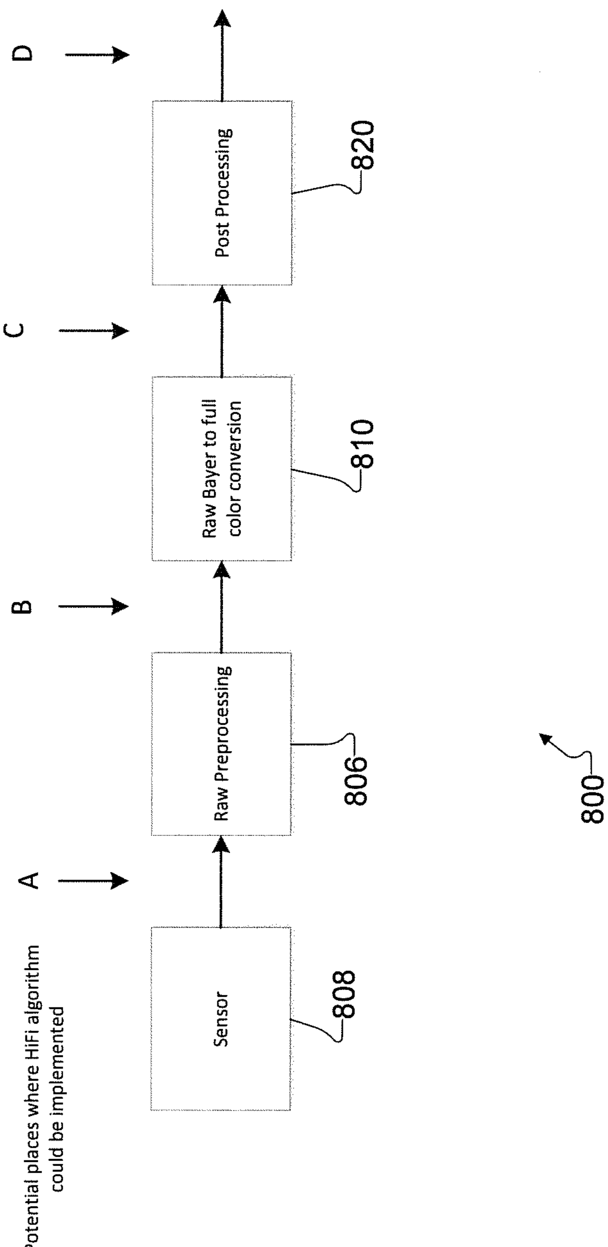

Potential places where HiFi algorithm could be implemented
A
B
C
D
Sensor
Raw Preprocessing
Raw Bayer to full color conversion
Post Processing
808
806
810
820
800

FIGURE 8

METHODOLOGY FOR GENERATING HIGH FIDELITY DIGITAL ZOOM FOR MOBILE PHONE CAMERAS

CROSS-REFERENCE TO RELATED APPLICATION(S) AND CLAIM OF PRIORITY

The present application claims priority to U.S. Provisional Patent Application Ser. No. 62/029,106, filed Jul. 25, 2014, entitled "METHODOLOGY FOR GENERATING HIGH FIDELITY DIGITAL ZOOM FOR MOBILE PHONE CAMERAS." The content of the above-identified patent document is incorporated herein by reference.

TECHNICAL FIELD

The present application relates generally to electronic imaging devices, and more specifically, to combining multiple images to generate an artifact free higher quality composite image.

BACKGROUND

Photography and camera users can benefit from a zoom capability of the camera and camcorder devices to achieve desired scene framing. Standalone cameras typically include optical zoom capabilities to achieve the effect of scene framing. Smartphone cameras are limited in thickness and cannot accommodate optical zoom systems, but instead and must rely on digital zoom technology to achieve the effect of scene framing.

Digital zoom technology on current smartphones does not provide good quality for high zoom factors, such as 4× zoom. There are many annoying quality problems including artifacts, noise, loss of detail, and unnaturalness. These quality problems result from the fact that high quality digital zoom requires sophisticated image processing technology that is computationally expensive, and the fact that typical digital zoom (or upscale) algorithms do not handle high zoom ratios very well.

SUMMARY

This disclosure provides an apparatus and method for generating High Fidelity Digital Zoom for mobile phone cameras.

In a first embodiment, a non-transitory computer readable medium embodying a computer program is provided. The computer program includes computer readable program code that, when executed by processing circuitry, causes the processing circuitry to capture, by a digital camera, a burst of N images. The computer program includes computer readable program code that, when executed by processing circuitry, causes the processing circuitry to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image, generate an interpolated image, and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio. Generating an interpolated image includes performing affine transformation using the set of affine matrices associated with the image. Generating an interpolated image includes applying an aliasing-retaining interpolation filter. Generating an interpolated image also includes implementing rotation transformation and sub-pixel shifts.

In a second embodiment, a mobile device includes an embedded digital camera that is configured to capture a burst of N images. The mobile device includes processing circuitry comprising a registration module configured to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image. The processing circuitry includes a High Fidelity Interpolation block configured to, for each image within the burst of images: perform affine transformation using the set of affine matrices associated with the image, apply an aliasing-retaining interpolation filter, and implement rotation transformation and sub-pixel shifts, yielding an interpolated image. The processing circuitry includes a blending module configured to receive the N interpolated images and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

In a third embodiment, system includes processing circuitry configured to couple to a mobile device comprising an embedded digital camera configured to capture a burst of N images. The processing circuitry comprises a registration module configured to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image. The processing circuitry comprises a High Fidelity Interpolation block configured to, for each image within the burst of images: perform affine transformation using the set of affine matrices associated with the image, apply an aliasing-retaining interpolation filter, and implement rotation transformation and sub-pixel shifts, yielding an interpolated image. The processing circuitry comprises a blending module configured to receive the N interpolated images and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

Before undertaking the DETAILED DESCRIPTION below, it may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The term "couple" and its derivatives refer to any direct or indirect communication between two or more elements, whether or not those elements are in physical contact with one another. The terms "transmit," "receive," and "communicate," as well as derivatives thereof, encompass both direct and indirect communication. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, means to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The term "controller" means any device, system or part thereof that controls at least one operation. Such a controller may be implemented in hardware or a combination of hardware and software and/or firmware. The functionality associated with any particular controller may be centralized or distributed, whether locally or remotely. The phrase "at least one of," when used with a list of items, means that different combinations of one or more of the listed items may be used, and only one item in the list may be needed. For example, "at least one of: A, B, and C" includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C.

Moreover, various functions described below can be implemented or supported by one or more computer programs, each of which is formed from computer readable program code and embodied in a computer readable medium. The terms "application" and "program" refer to one or more computer programs, software components, sets of instructions, procedures, functions, objects, classes, instances, related data, or a portion thereof adapted for implementation in a suitable computer readable program code. The phrase "computer readable program code" includes any type of computer code, including source code, object code, and executable code. The phrase "computer readable medium" includes any type of medium capable of being accessed by a computer, such as read only memory (ROM), random access memory (RAM), a hard disk drive, a compact disc (CD), a digital video disc (DVD), or any other type of memory. A "non-transitory" computer readable medium excludes wired, wireless, optical, or other communication links that transport transitory electrical or other signals. A non-transitory computer readable medium includes media where data can be permanently stored and media where data can be stored and later overwritten, such as a rewritable optical disc or an erasable memory device.

Definitions for other certain words and phrases are provided throughout this patent document. Those of ordinary skill in the art should understand that in many if not most instances, such definitions apply to prior as well as future uses of such defined words and phrases.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates an example user equipment for generating High Fidelity Digital Zoom for a mobile phone camera according to this disclosure;

FIG. **2** illustrates a block diagram of components within the user equipment of FIG. **1** for implementing the High Fidelity Digital Zoom;

FIG. **3** illustrates a burst of images captured according to this disclosure;

FIG. **4** illustrates a block diagram of a High Fidelity Digital Zoom system according to this disclosure;

FIG. **5** illustrates a block diagram of a configuration of the user equipment of FIG. **1** in accordance with this disclosure;

FIG. **6** illustrates a process for selecting a HiFi Zoom algorithm in the example user equipment of FIG. **1** according to this disclosure;

FIG. **7** illustrates a process for custom tuning and control of camera firmware according to this disclosure; and

FIG. **8** illustrates various places within an imaging processing architecture where a HiFi Digital Zoom system and algorithm could be implemented an example user equipment according to this disclosure.

DETAILED DESCRIPTION

FIGS. **1** through **8**, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of this disclosure may be implemented in any suitably arranged device or system.

Examples of single frame interpolation methods for implementing digital zoom include bilinear interpolation, bicubic interpolation, or other directionally adaptive interpolation. These methods operate on single frame only.

There are multi-frame interpolation methods for implementing digital zoom that rely on complicated iterative algorithms. These iterative multi-frame interpolation methods are not suitable for implementation on mobile phones due to the computational complexity of iterative algorithms. Moreover, these iterative algorithms cannot handle moving objects as the moving objects move from frame to frame.

Embodiments of the present disclosure provide a methodology of producing High Fidelity (HiFi) Digital Zoom images on mobile phones. Embodiments of the present disclosure provide an improved user interface, a system use case implementation, and a multi-frame computational imaging algorithm to improve the quality of digitally zoomed images. Embodiments of this disclosure also provide the application, a user experience design, camera firmware configuration, algorithm and implementation for enabling a combining of multiple images to generate artifact free high quality image as well as a multi-frame registration system for aligning and blending image captures. Embodiments of this disclosure also produce zoomed images that have better image rendering, improved noise profile, more natural texture rendering, and improved clarity of objects in the zoomed image. The multi-frame computational imaging algorithm is able to handle moving objects in the scene as well as camera motion from frame to frame. The multi-frame computational imaging algorithms perform well in terms of computational complexity and memory footprint in embedded implementations (for example, embedded in a mobile phone).

By way of comparison to the single frame interpolation methods and to the iterative multi-frame interpolation methods of implementing digital zoom, the embodiments of this disclosure not only produce high quality images, but also do not suffer from the complexities and limitations of existing multi-frame methods described above. As such, embodiments of the present disclosure provide the user with significantly better user experience.

FIG. **1** illustrates an example user equipment (UE) for generating High Fidelity Digital Zoom for a mobile phone camera according to this disclosure. Although certain details will be provided with reference to the components of the user equipment **100**, it should be understood that other embodiments may include more, less, or different components.

The UE **100** includes a display **102** and an embedded camera **200** disposed on the front side of the UE. The display **102** displays information of an application executed by the processing circuitry of the UE **100**. The camera **200** captures images in a high resolution digital format, but the camera **200** is not configured to perform an optical zoom. The UE **100** includes processing circuitry, including one or more processors and memory, configured to control an operation of the UE **100**, control an operation of the display **102** and control and operation of the camera **200**. The UE **100** can include independent processing circuitry **100** for each of the display **102**, camera **200** and for control of the UE **100** that are configured to intercommunicate and cooperate with each other to perform one or more functions described herein. In certain embodiments, one of more of the display **102**, camera **200** and UE **100** control functions are performed by a common, or shared, processing circuitry.

FIG. **2** illustrates a block diagram of components within the user equipment of FIG. **1** for implementing the High Fidelity Digital Zoom. The embodiment of components within the UE **100** shown in FIG. **2** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

The camera **200** includes a camera controller with firmware **202**, burst capture module **204**, an affine registration module **206**, a sensor **208**, an image signal processor (ISP) **210**, an ISP rescaler **212**, and an input/output (I/O) interface **214**. The camera **200** is connected to the High Fidelity Digital Zoom system **400** in order to operate in a High Fidelity Zoom mode ("HiFi mode") and to receive control signals **216** from, and send control signals **218** and a burst of images **300** to the HiFi Digital Zoom system **400**. The I/O interface **212** receives data from and sends data to the I/O interface of the HiFi Digital Zoom system **400**.

High Fidelity Zoom is a special mode on a camera application of a mobile phone or UE **100**. High Fidelity Zoom mode can be automatically selected based on zoom ratio (for example, >2×) or automatically selected based on a photographic mode or selected manually by the user. Herein, automatic refers to action resulting from a prior operation without human operator intervention. For example, the camera **200** can automatically (namely, without human interaction) select to operate in HiFi mode in response to a determination that the zoom ratio exceeds a threshold value. The threshold value may indicate a maximum zoom ratio of the non-HiFi normal mode of the camera. Once the HiFi mode is selected and the user zooms in to take a picture, the camera application engages the focus, locks (i.e., prevents from changing) exposure and color control, switches sensor mode back to a 1× zoom ratio, configures the camera firmware to an application-specific "tuning" parameter set, and captures a burst of images **300**. Despite the fact that the user tries determinedly to keep the camera stable, the user cannot avoid micro-movements of the camera. These micro-movements cause the camera **200** to capture the burst of images **300** wherein each image is from a slightly different position. While the burst of images **300** is being captured, the camera application can indicate to the user to not to move the phone away from the scene of which the images are being captured. Once the High Fidelity Zoom algorithm (also referred to as a multiple stage zoom algorithm described more particularly below in reference to FIG. **4**) has been applied to the burst of images, the resulting composite image **250** is displayed to the user or saved in the memory of the UE **100** for the camera application photo gallery.

The camera controller with firmware **202** includes signal processing circuitry and a memory within the UE **100** that stores program code that provides the control program of the camera **200**. The camera controller with firmware **202** controls the functions of each of the other camera components **208-214** using control signals or control parameters. In HiFi mode, the camera application configures the camera firmware **202** to perform auto-exposure lock, auto-focus lock, and auto-white/color balance lock (collectively called 3A lock) while the burst of images is captured. For example, the camera firmware **202** sends sensor control parameters **220** to the sensor **208** to implement the 3A lock while capturing a burst of images. The 3A lock ensures that the High Fidelity Zoom algorithm does not have to normalize the individual images within the burst **300** for variations in brightness or colors across the set of images in the burst **300**. The 3A lock removes the need for brightness normalization, color normalization, and scale normalization in multi-frame blending algorithms.

In a non-HiFi mode, when the user zooms in to take a picture, the image output from the ISP **210** is output from the ISP Rescaler **212** at the selected zoom ratio (for example, 1.3×) that is greater than 1×. In HiFi mode, the camera application instructs the camera firmware **202** to switch mode back to a 1× zoom ratio and output smaller resolution buffers. More particularly, when the user zooms in to take a picture at a zoom ratio (for example, 4×) high enough for the camera **200** to implement HiFi mode, the firmware **202** generates ISP control parameters **224** that cause the ISP **210** to output each image in the burst of images **300** at a 1× zoom ratio. The 1× resolution images enable the High Fidelity Digital Zoom system **400** to perform interpolation and processing on the burst of images **300**. The camera application reconfigures the camera firmware **202** to generate "tuning" parameters **224** that are more suitable for image texture retention. The custom "tuning" parameters **224** include parameters for defect pixel correction, noise filtering, color filter array interpolation (demosaicing), sharpness enhancement, and so forth. These custom tuning parameters **224** retain image information but may produce undesirable image effects in a single image **228**. The undesirable effects are mitigated through blending of multiple frames, while the benefits (improved texture rendition) are not reduced by multi-frame blending. Re-configuration of the camera firmware **202** enables the ISP **210** to perform reduced noise filtering, reduced pixel defect correction, and reduced interpolation aliasing cancellation. Re-configuration of the camera firmware **202** causes the ISP **210** to generate poorer quality images compared to a normal photo capture scenario, but also, the High Fidelity Digital Zoom system **400** produces a higher fidelity output composite image **250** by blending multiple images of the burst of images **300**. As described more particularly below with reference to FIG. **4**, the blending operation effectively includes noise filtering, defect pixel reduction, and aliasing reduction. The ISP tuning parameters **224** cause each image of the burst **300** to have poorer quality than the blended output composite image **250**.

The burst capture module **204** enables the camera **200** to capture a burst of images **300** also referred to as a burst of frames). More particularly, the burst capture module **204** enables the camera **200** to rapidly capture several photographs in succession. For example, the burst capture module **204** enables the camera **200** to capture to 30 frames per second. In certain embodiments, the burst capture module **204** enables the camera **200** to captured 5 frames within 150 milliseconds (ms). The burst capture module **204** stores each burst of images **300** in a memory in the UE **100**. In certain embodiments, the burst capture module **204** enables the camera **200** to continuously capture images in quick succession. In certain embodiments, the burst capture module **204** enables the camera to capture a burst of images in response to a user input, such as pressing a shutter button or holding the shutter button. When the camera operates in HiFi mode, the burst capture module **204** enables to the sensor **208** to rapidly capture images.

The sensor **208** can be an image sensor that captures an image **222** by converting light to an electric signal. The sensor **208** receives sensor control parameters **220** from the camera controller with firmware **202** to control the exposure, white/color balance, and focus. In HiFi mode, in response to receiving sensor control parameters **220**, the sensor **208** implements the 3A lock while capturing each of the images during the burst capture period.

The ISP **210** receives each raw image **222** captured by the sensor **208** and receives parameters **224** to control the quality of the images output from the ISP **210**. Based on the parameters **224**, the ISP **210** leaves the images in raw format or improves the quality of each raw image **222** by applying a noise reduction filter, a defect pixel correction, a color filter array interpolation (for example, demosaicing), and a sharpness enhancement process. The ISP outputs the processed image **228** to the HiFi Digital Zoom system **400**. The parameters **224** can be generated by and received from the HiFi Digital Zoom system **400** or the camera controller with firmware **202**. In the non-HiFi mode, the ISP **210** receives parameters **224** from the camera controller with firmware **202**, which are parameters that cause the ISP **210** to remove noise and aliasing from images and to output high quality images. As described more particularly below, the HiFi Digital Zoom system **400** includes one or more pre-processing components, such as a noise filter and a pre-sharpener. Accordingly, when operating in the HiFi mode, the camera **200** need not duplicate the noise and aliasing removal that occurs in the pre-processing components of the HiFi Digital Zoom system **400**. In certain embodiments, the noise filtering and pre-sharpening is part of the ISP **210**, which can be placed under appropriate control of the HiFi system. That is, in the HiFi-mode, the ISP **210** receives parameters **224** from the HiFi Digital Zoom system **400**, which are parameters that cause the ISP **210** to remove a lesser amount of noise and aliasing than the amount of noise and aliasing that would be removed by the parameters generated by the camera controller with firmware **202**. In certain embodiments, parameters **224** from the HiFi Digital Zoom system **400** cause the ISP **210** to bypass the noise removal, the aliasing removal, or both noise and aliasing removals. Accordingly, the images output from the ISP **210** in HiFi mode may have more noise or aliasing than the images output from the ISP **210** in non-HiFi mode.

The ISP rescaler **214** rescales the resolution of the image output from the ISP **210** to a user-selected zoom ratio (for example, 1.2× or 4×) and provides the resealed image **226** to the display **102**. In non-HiFi mode, the ISP rescaler **214** additionally sends the resealed image **226** to the memory of the UE **100** for saving in the camera application photo gallery. In certain embodiments, the ISP rescaler **214** is included within the ISP **210**. When the ISP **214** is part of the ISP **210**, in HiFi mode, the ISP **210** outputs the image to the I/O interface **214** at a 1× resolution and outputs the image at a selected resolution (for example, 4×) to the display **102** of the UE **100** through the ISP rescaler **212**.

The affine registration module **206** detects uniform distortion between images and registers a set of points where the distortion is present. For example, when the UE **100** is in the hand of a user while capturing multiple images of the same scene, a first image of the scene is captured while the camera **200** was horizontally level at a 0° angle, yet due to a slight movement of the user's body, the camera moves to a 3° angle to capture the second image of the scene. The affine registration module **206** can use the first image as a reference frame to detect the points in the second image of the scene that are slightly displaced compared to the position of the point in the first image reference frame. The affine registration module **206** receives each image **222** captured by the sensor **208**, and then outputs camera affine information including the set of displaced points and the corresponding amounts by which the displaced points were linearly and/or angularly translated. In certain embodiments the High Fidelity Digital Zoom system **400** receives and uses the camera affine information to perform a HiFi registration process.

The HiFi Digital Zoom system **400** receives a burst of images **300** from the camera **200**, and then uses the burst of images **300** to generate a composite image **250**. The HiFi Digital Zoom system applies a multiple stage zoom algorithm to the burst of images **300**. The multiple stage zoom algorithm includes a multiple-stage blending algorithm and a single-frame interpolation algorithm. The multiple-stage blending includes an alignment estimation stage, and an interpolation and blending stage. The HiFi Digital Zoom system **400** is described if further detail in reference to FIG. **4**.

In the example shown, the camera firmware **202** implements the HiFi Zoom as the last stage of the image processing pipeline, after the images are captured, and after the ISP **210** makes corrections to the image. In other embodiments, the HiFi Zoom can be an intermediate stage, or the first stage of the processing pipeline.

FIG. **3** illustrates a burst of images captured according to this disclosure. The embodiment of the burst of images **300** shown in FIG. **3** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

The burst of images **300** includes a number N of images. For example, if N=5, then the burst of images **300** includes a first image **302** (IMG_0), a second image **304** (IMG_1), a third image **306** (IMG_2), a fourth or penultimate image **308** (also shown by an ellipsis indicating images between the third and last images of the burst), and a fifth or last image **310** (IMG_{N-1}). The camera **200** captures the burst of images during a burst capture period **312**, which represents the amount of time that elapses from the time the camera **200** commences to capture the first image **302** and the time the camera **200** finishes capturing the last image **310** of the burst.

FIG. **4** illustrates a block diagram of a High Fidelity Digital Zoom system according to this disclosure. The embodiment of the High Fidelity Digital Zoom system **400** shown in FIG. **5** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure.

The High Fidelity Digital Zoom system **400** receives the burst of images **300** from the camera **200**. For example, for each image captured during the burst capture period **312**, the ISP **210** provides the processed image **228** to a buffer that stores the N processed images **302-310**. That is, during processing of the burst of images **300**, a first processed image **228***a* is stored in the buffer as the first image **302** (Image **0**), and in a similar manner, subsequently processed images **228***b*-**228***e* are stored in the buffer as the second through $(N-1)^{th}$ image **304-310** (Image **1**, Image **2**, Image **3**, and Image **4**).

The High Fidelity Digital Zoom system **400** relies on the fact that when a hand-held camera performs a high speed burst capture of a scene, each image is captured from a slightly different position of the camera due to slight hand-shake of the user. The multiple stage zoom algorithm contains two or more stages of processing blocks: an image alignment estimation stage and an interpolation/blend stage. The image alignment estimation stage performs registration of the multiple frames in the burst of images **300**. In certain embodiments, the first frame **302** in the burst sequence **300** is considered to be the reference frame, and all other frames in the burst **300** are registered with the reference frame using standard image registration methods of feature detection, tracking, and transformation estimation. The Interpolation/Blend stage uses the result of the transform estimation.

The High Fidelity Digital Zoom system **400** includes a reference frame selection module **402**, a buffer **404**, a pre-processing block including a noise filter **406** and a pre-sharpener **408**, a registration module **410**, a scene analysis block **412**, a HiFi Interpolation block **414**, a Local Motion Analysis block (also referred to as a Smart Fusion block) **416**, a blending module **418**, a post-processing block

420, and a second scaling block **422**. The components of the High Fidelity Digital Zoom system **400** can be implemented by one or more processors, a processor array, with suitable memory and instructions contained therein, or any suitable processing circuitry configured to perform the functions of the respective component blocks, either independently or collectively.

The reference frame selection module **402** selects a reference frame from the burst of images **300**. After making the selection, the reference frame selection module **402** can store the reference frame in a buffer **404** to provide access to the pre-processing block and to components of the image alignment estimation stage. The reference frame selection module **402** can select the first frame **302** received by the High Fidelity Digital Zoom system **400** to be the reference frame in order to reduce performance time (namely, the amount of time between receiving the first frame **302** into the High Fidelity Digital Zoom system **400** and outputting the composite image **250**). Waiting to receive subsequent images **304-310**, which serially processing through the ISP **210**, before selecting a reference frame increases performance time. Alternatively, the reference frame selection module **402** can analyze the sharpness of all of the images in the burst **300** and selected the sharpest frame to be the reference frame. The reference frame selection module **402** selects the sharpest frame in order to establish a high threshold to which the non-reference images are compared to increase the quality of the composite image **250**. As shown, the reference frame selection module **402** can select the middle frame **306** to be the reference frame, for example, by selecting the third image **306** (Images **2** Reference) when the burst of images **300** includes N=5 images. In certain embodiments, the reference frame selection module **402** selects a specified frame number to be the reference frame. Examples of specified frame numbers include the N^{th} frame (i.e., last frame), the middle frame ($N/2^{th}$), the first frame, or any other frame number within the burst of N images. In certain embodiments, the reference frame selection module **402** selects as the reference frame the image having the least motion difference from other images in the burst of N images **300**. For example, the reference frame selection module **402** uses the affine information output from the affine registration module **206** of the camera **200** to determine the image having least displacement or least motion difference. In certain embodiments, the reference frame selection module **402** selects the sharpest frame when the High Fidelity Digital Zoom system **400** has received at least half of the burst of images **300**, thereby reducing performance time compared to selecting from the all images in the burst and increasing image quality compared to selecting the first frame, which may not be the sharpest.

The pre-processing block improves the process of implementing the later stages, such as the image alignment estimation stage and interpolation and blending stage. The noise filter **406** removes noise from each image in the burst of images **300**. Accordingly, the noise filter **406** reduces the amount of noise processed within the later stages. The output from the noise filter **406** is a noise-filtered version **300***a* of the burst of images having N images. Accordingly, the pre-sharpener **408** reduces the amount of blur processed within the later stages. The output from the pre-sharpener **408** is a pre-sharpened version **300***b* of the burst of images having N images.

The image alignment estimation stage includes the registration module **410**, and the scene analysis block **412**. In certain embodiments, image alignment estimation stage uses feature detectors and tracking for image registration and alignment. That is, the image alignment estimation stage jointly uses feature detection and tracking and local motion estimation.

The registration module **410** analyzes the burst of images **300** for warp and generates a set of affine matrices **430** for each image within the burst of images, for a total of N sets of affine matrices. For each image **302-310**, the set of affine matrices **430** indicates an amount by which each image is warped compared to the reference image **306**. More particularly, the set of affine matrices **430** indicate the displaced points within the non-reference image and the corresponding amounts by which the displaced points were linearly and/or angularly translated compared to the reference image. The registration module **410** sends the affine matrices **430** of each image to the HiFi Interpolation block **414**, where the linear or angular translation of the displaced points is corrected.

The scene analysis block **412** determines an amount of motion occurring within the scene captured in the burst of images. The scene analysis block **412** receives the affine matrices **430** from the registration module **410**, and uses the affine matrices **430** to avoid interpreting warp as object motion within a scene. For example, if the user uses the burst capture to take a picture of a mountain scene with a clear sky (for example, no visible clouds), the scene analysis block **412** can determine that nothing in the scene is moving because in all N=5 images, the mountains and ground are stationary, and no visible clouds are moving. As another example, if the user takes a picture of the same mountain scene, yet during two of the five images, an insect flies across a horizontal centerline of the scene within view of the camera **200** lens or sensor **208**, then the scene analysis block **412** can determine that small amount (namely, one insect object, one direction, few frames) of movement is occurring in the scene. As another example, if the user takes a picture of the same mountain scene, yet in all of the images **303-310**, tree foliage being blown in various directions by wind occupies a top right-hand corner of the view of the camera lens or sensor **208**, then the scene analysis block **412** can determine that a large amount (namely, several leaf objects, various directions, all frames) of movement is occurring in the scene.

The scene analysis block **412** selects which images within the burst of images **300** will be blended together to form the composite imaged **250**. That is, the scene analysis block **412** selects which images to not transfer to the blending module **418**. In response to determine that an image has too much motion, in order to improve the blending process, the scene analysis block **412** can select to drop the image from being transferred to the blending module **418**. More particularly, the scene analysis block **412** also provides blend control parameters **432** to the blending module **418** indicating a weight of each image in the burst **300**. The weight indicates the strength that blending module **418** should apply to corresponding image. An image with a zero weight can be eliminated from the blending process or not relied upon by the blending module **418**, and an image with a largest weight can be relied upon heavily for the blending process.

The scene analysis block **412** generates motion control parameters **434** for the Smart Fusion block **416** that uses the motion control parameters **434** to identify the pixels within an image that constitute a moving object within a scene, such as the flying insect or tree foliage.

The interpolation and blending stage includes the HiFi Interpolation block **414**, the Smart Fusion block **416**, the blending module **418**. The interpolation and blending stage computes a set of locally adaptive weights from the transformation estimation. The weights are estimated from an aliasing-retaining interpolation filter, a sharpening filter, a rotation transformation, an upscale transformation, and a sub-pixel image shift. After each frame in the burst **300** has been processed through the locally adaptive weights, the entire set of images **300** is blended together through an average operation to produce a single blended image **440**. In certain embodiments, the interpolation and blending stage uses different ISP tuning settings (such as noise filtering or sharpness enhancement) for determining local weights for the local motion determination, but also uses different ISP tuning settings for generating images before blending.

The HiFi Interpolation block **414** compensates or otherwise corrects for affine motion in each image. That is, for each image in the burst of images **300**, the HiFi Interpolation block **414** uses the affine matrices associated with that image to generate an unwarped and upscaled version of that image. That is, the output from the pre HiFi Interpolation block **414** is an interpolated version **300***c* of the burst of images having N images. The HiFi Interpolation block **414** upscales the burst of images by a zoom ratio of approximately 1.5× such that the interpolated version **300***c* of the burst of images has a larger number of pixels than the burst of images **300**. The HiFi Interpolation block **414** includes an aliasing-retaining interpolation filter that comprises a polyphase implementation of digital upscale with a cut-off low-pass filter that is designed to extend well beyond the typical Nyquist frequency, and passes through a significant portion of the first alias. The aliasing-retaining interpolation filter deliberately does not filter out the aliasing components when performing interpolation. The retention of aliasing can be partial or complete, but retaining aliasing in the burst of images until the blending process is intentional in filter design for the HiFi digital zoom. The aliasing retention of the HiFi Interpolation block **414**, which is objectionable in a single-frame interpolation algorithm from a quality perspective, helps retain image features and resolution when multiple frames are blended. Blending multiple frames cancels the alias while preserving image features. That is, the single-frame interpolation algorithm and the iterative multi-frame interpolation methods described above do not include aliasing cancellation through blending of multiple frames.

The HiFi Interpolation block **414** implements rotation transformation and sub-pixel shifts through bicubic weight generation based on coordinate transformation. Together with the interpolation filter described above, these rotation transformation and sub-pixel shifts constitute an affine transformation of the image. Splitting an affine transform into upscale and rotate/shift operations, implementing upscale through aliasing-retaining interpolation algorithm, and sharpening before rotation/shift operation are technical advantages of the HiFi Interpolation block **414**. The HiFi Interpolation block **414** performs these technically advantageous operations with different characteristics, thereby optimizing output quality while reducing computational load.

In certain embodiments, High Fidelity Digital Zoom system **400** includes a combination of all stages (rotation, shifts, upscaling and sharpening) into one set of locally adaptive weights. In certain embodiments, High Fidelity Digital Zoom system **400** includes a processing block that is combination of aliasing-retaining interpolation, sharpening, rotation, and sub-pixel shifts algorithms that produce one set of locally adaptive weights. The locally adaptive weights are pre-computed, and applied based on pixel shifts from coordinate transformations. A Look-up-Table based method is used to fetch the local weights that are applied in the implementation.

The HiFi Interpolation block **414** uses the locally adaptive weights for upscaling (interpolation), sharpening, rotation, and shifts (integer pixel or sub-pixel) frames. In certain embodiments, the HiFi Interpolation block **414** performs upscaling, sharpening, rotation and shifts as separate operations. In other embodiments, the HiFi Interpolation block **414** performs upscaling, sharpening, rotation and shifts as combined operations in another order. For example, the HiFi Interpolation block **414** can include a combination of upscaling interpolation, sharpening, rotation, and shifts into one set of locally adaptive weights, and a combination of sub-sets into different sets of weights. In certain embodiments, the HiFi Interpolation block **414** processes the N images in the burst of images **300** with a different set of locally adaptive weights depending on affine matrices **430** (i.e., the image registration parameters). In certain embodiments, the HiFi Interpolation block **414** uses locally adaptive weights to implement a geometric transformation (affine or projective/perspective), with sharpening filter in between. In certain embodiments, the HiFi Interpolation block **414** splits the geometric transformation to implement one aspect of interpolation through specialized interpolation kernels (such as an aliasing retaining upscaling kernel) and implement other aspects of the transformation through standard methods (for example bilinear or bicubic or other) or specialized methods.

The Smart Fusion block **416** applies a local motion handling algorithm to the interpolated **300***c* burst of images to determine which sub-parts of the image have moving objects. The Smart Fusion block **416** generates a weight map or local motion map **436** that indicates which parts of an image have motion and which parts do not. The Smart Fusion block **416** outputs local motion maps **436** to the blending module **418** and to the post-processing block **420** to indicate the location of each pixel that constitutes a moving object. The Smart Fusion block **416** applies a local motion handling algorithm to analyze the local motion within each image in the interpolated burst of images **300***c*. For example, the Smart Fusion block **416** can determine the location of each pixel that constitutes the flying insect or the blowing tree foliage described in examples above. As another example, the Smart Fusion block **416** can determine the location of each pixel that constitutes a person walking through a scene and distinguish the pixels of the person from the pixels of a stationary background, such as mountains. The Smart Fusion block **416** implements an algorithm to determine the locally adaptive weights. The Smart Fusion block **416** improves performance and accuracy by using up-sampled or down-sampled images for determining the local weights for local motion determination.

The blending module **418** uses local motion maps **436** to ensure that moving objects are not blended together. The blending module **418** receives the interpolated burst of images **300***c* and blends the N images into a single-blended image **440**. Though the blending module **418** can receive all N images, the blend module **418** may exclude an image from the blend process based on the blend control parameters. The location of a pixel in the first image (Image **0**) of the interpolated burst of images **300***c* is the same location of that pixel in the other images in the interpolated burst **300***c*. Accordingly, each location of a pixel can be either: (1) a high quality pixel selected from the reference frame **306** to be an unblended, or (2) a blend of up to N pixels from the same location in each of the N images in the interpolated burst **300***c*. For each pixel location, the location motion maps **436** indicate whether a pixel will be blended or not. For each of the N images, the blend control parameters **432** indicate which images with be used for the blend process and a how much weight is assigned to pixels from each image. The single-blended image **440** can include blended pixels at certain locations and unblended pixels at other locations. The blending module **418** uses a weighted averaging operation to perform the blending operation. The multi-frame blending operation performs aliasing cancellation, defect pixel correction, and signal to noise ratio improvement (noise filtering). The local motion maps **436** include weights for the blending function that are determined by the local motion handling algorithm of the Smart Fusion block **416**. The blending module **418** uses statistical estimation techniques such as mean, median or other statistic for the purpose of blending multiple images. For example, the blending module **418** can compute the statistical mean (or average) on-the-fly and use the mean as a computationally efficient statistic for blending. The blending module **418** is not limited to uses the statistical average (for example, mean or median), but also can use a standard deviation, a minimum, or a maximum statistic as a computationally efficient statistic that can be computed on-the-fly, or any other statistic computed from the pixels coming from N frames.

In certain embodiments, the HiFi Digital Zoom system **400** uses aliasing retention in a single frame and aliasing cancellation through multiple frames jointly in one application. In other applications, the HiFi Digital Zoom system **400** uses aliasing retention in a single frame separately from aliasing cancellation through multiple frames.

The post-processing stage includes a post-processing block **420** and the second scaling block **422**. The post-processing block **420** includes a post-sharpener, a contrast analyzer, and a saturation estimator. The sharpening filter of the post-processing block **420** enhances image details in the interpolated image, and it helps improve sharpness in the overall output composite image **250**. A high-pass/band-pass filter is implemented as the sharpening filter. The cut-offs of the filter are visually optimized for a most pleasing output quality. In certain embodiments, the HiFi Digital Zoom system **400** uses a sharpening filter before **408** and after **420** the interpolation algorithm **414** to improve output quality of the composite image **250**. In certain embodiments, the HiFi Digital Zoom system **400** enhances image fidelity by using a sharpening filter designed together with the aliasing retaining interpolation filter.

The second scaling block **422** receives a sharpened version **440***a* of the single-blended image. The second scaling block **422** up-scales the blended image **440***a* by a remainder zoom ratio using a single-frame interpolation algorithm, such as a bicubic method or other interpolation method. The output from the second scaling block **422** is the composite image **250** at a resolution requested by the user, such as a 9× or 4× resolution of digital zoom. For example, if a user zooms in to a 9× zoom ratio to take a burst of pictures of a scene, then the HiFi Interpolation block **414** applies a 1.5× upscaling such that the blended image **440***a* needs to be further up-scaled by a remainder 6× zoom ratio for a 9× total zoom ratio. In this example, the total zoom ratio÷the first stage upscaling zoom ratio=the remainder zoom ratio.

According to this disclosure, the High Fidelity Digital Zoom system **400** implements a two-stage digital zoom algorithm including a non-iterative multi-stage blending followed by a single-frame interpolation. The two-stage digital zoom algorithm reduces the complexity of the overall algorithm because a substantial portion of the image quality improvement is realized at a smaller resolution. That is, the image processing occurs at the 1× or 1.5× resolution until the last stage, namely, the second scaling block **422**. By comparison, image processing that occurs at the resolution requested by the user (for example, 4× or 9×) increases the processing complexity.

FIG. **5** illustrates a block diagram of a configuration of the user equipment of FIG. **1** in accordance with this disclosure. The embodiment of the UE **100** shown in FIG. **5** is for illustration only. Other embodiments could be used without departing from the scope of the present disclosure. UEs come in a wide variety of configurations, and FIG. **5** does not limit the scope of this disclosure to any particular implementation of a UE. For example, the UE **100** can be a mobile phone including a smart phone, MP3 terminal, tablet PC, and various digital equipment having an embedded camera.

The UE **100** includes an antenna **505**, a communication unit **510**, a first camera **515**, a second camera **200**, an audio unit **525**, a display unit **102**, an input interface **530**, sensor **535**, memory **540**, and processor **545**.

The communication unit **510** performs a communication function with a base station or internet server. Further, the communication unit **510** includes a modulator and a demodulator. The modulator transmits a transmitting signal to the transmitter by modulating the signal, and the demodulator demodulates a signal received through the receiver. Here, the modulator and demodulator can be a Long Term Evolution (LTE), Wideband Code Division Multiple Access (WCDMA), Global System for Mobile Communications (GSM), Wireless Fidelity (WIFI), Wireless Broadband (WiBro), Near Field Communication (NFC), or BLUETOOTH (Bluetooth). In the embodiments of the present disclosure, the communication unit **510** is configured with LTE, WIFI, and Bluetooth devices.

The first camera **515** is a camera disposed at the rear side of the portable terminal, and can photograph a high resolution image. The second camera **200** is a camera disposed at the front side of the portable terminal, and can digital photograph.

The audio unit **525** includes a microphone and a speaker. An audio unit **525** processes voice signals generated in a communication mode and processes an audio signal generated in a photographing mode of the camera.

A display unit **102** displays information of an executing application under the control of the processor **545**. The display unit **102** may be a liquid crystal display (LCD), OLED, or other display capable of rendering text and/or at least limited graphics, such as from web sites. The input interface **530** is provided with a capacitive type or resistive type, and outputs location information of user's touch (finger touch) to the processor **545**. Further, the input interface **530** can include an EMR sensor pad, and detects a pen touch input to transmit to the processor **545**. Here, the display unit **102** and input interface **530** can be integrated into one unit. The input interface **530** can include a keypad that the operator of the UE **100** can use a keypad to enter data into the UE **100**.

A sensor **535** can include various sensors for detecting movement of the portable terminal. The sensor **535** can be configured with an acceleration sensor, geomagnetic sensor, and/or location detection sensor.

The memory **540** includes an operating system (OS) program **550** and one or more applications **555**, such as a camera application. The memory **540** is coupled to the processor **545**. Part of the memory **540** could include a random access memory (RAM), and another part of the memory **540** could include a Flash memory or other read-only memory (ROM). The memory **540** has a program memory storing the operating system **550** of the UE **100** and a camera application **555** according to embodiments of the present disclosure, and a data memory storing tables for the operation of the UE and data generated while executing a program.

The camera application **555** provides a specialized multi-frame technology used to produce high fidelity zoom that produces images with improved signal-to-noise ratio, lower aliasing, improved rendering of curvy and angled objects, and improved clarity. The camera application **555** relies on user-handshake (small un-intended micro-movements of the hand) to capture multiple images of a scene from slightly different camera position, and uses computational methods to take advantage of the additional information contained in these images coming from slightly different perspectives and produces high fidelity zoom images. The camera application **555** uses a combination of multi-frame high fidelity zoom and regular non-HiFi digital zoom in a two-stage fashion to reduce complexity or extend zoom ranges.

The processor **545** can include one or more processors or other processing devices and execute the OS program **550** stored in the memory **540** in order to control the overall operation of the UE **100**. In some embodiments, the processor **545** includes at least one microprocessor or microcontroller. The processor **545** controls the general operation of the UE **100**, and controls a function of generating High Fidelity Digital Zoom for a mobile phone camera according to an embodiment of the present disclosure. That is, the processor **545** is also capable of executing other processes and programs stored in the memory **540**, such as operations for generating High Fidelity Digital Zoom for a mobile phone camera. The processor **545** can move data into or out of the memory **540** as required by an executing process. In some embodiments, the processor **545** is configured to execute the applications **555** based on the OS program **550** or in response to signals received from a base station or an operator. The processor **545** is also coupled to the display unit **102**. In the UE **100**, the processor **545** obtains a still image or moving image by controlling the first camera **515** and/or second camera **200**. The processor **545** controls the display unit **102** to display the image selected in an edit mode and to display soft buttons to select a burst capture mode or a HiFi Digital Zoom mode for the camera **200**.

Although FIG. **5** illustrates one example of UE **100**, various changes may be made to FIG. **5**. For example, various components in FIG. **5** could be combined, further subdivided, or omitted and additional components could be added according to particular needs. As a particular example, the processor **545** could be divided into multiple processors, such as one or more central processing units (CPUs) and one or more graphics processing units (GPUs). Also, while FIG. **5** illustrates the UE **100** configured as a mobile telephone or smartphone, UEs could be configured to operate as other types of mobile or stationary devices.

FIG. **6** illustrates a process for selecting a HiFi Zoom algorithm in the UE **100** according to this disclosure. The embodiment of process **600** shown in FIG. **6** is for illustration only. While the flow chart depicts a series of sequential steps, unless explicitly stated, no inference should be drawn from that sequence regarding specific order of performance, performance of steps or portions thereof serially rather than concurrently or in an overlapping manner, or performance of the steps depicted exclusively without the occurrence of intervening or intermediate steps. The process depicted in the example depicted is implemented by processing circuitry chain in, for example, a UE.

In block **605**, the camera application starts, such as application **555**. That is, the processor **545** executes the camera application **555**.

In block **610**, the user zooms into a picture. That is, the user uses the input interface of the touchscreen display **102** to zoom on a scene to a user desired zoom ratio, such as 9×. In response, the ISP rescaler **212** produces the 9× zoomed images on the display **102** of the UE **100**. At the same time, the camera firmware **202** determines that the user has enabled zoom, and determines that the user desired zoom ratio (e.g., 9×) is greater than a threshold value (for example, 1.5×) at which the camera **200** automatically enables HiFi mode. Accordingly, the camera initiates HiFi mode in response to the user clicking on a capture button to take a 9× zoom picture of a scene. In certain embodiments, the camera **200** initiates HiFi mode in response to a manual user selection to enter HiFi mode. For example, the user can use a camera setting menu option to select enabling or disabling high fidelity zoom.

In block **615**, the user clicks on the capture button. In response, the camera firmware **202** engages in a custom camera control, such as the burst capture module **204**, to capture a burst of images **300**. After the burst capture is completed, the camera firmware **202** returns to a default setting to continue to send zoomed images to the display, for example, zoomed to the user desired zoom ratio.

In block **620**, a zoomed capture image is saved to the UE memory **540**. For example, the HiFi Digital Zoom system **400** processes the burst of images **300** in the background operations of the UE **100**. That is, the HiFi Digital Zoom system **400** receives images from the camera pipeline that are captured at a 1×, un-zoomed, resolution, yet the user only sees the user desired zoom ratio on the display **102**. The display does not automatically present data to the user indicating that the images are not captured at 9× zoom, but instead captured at 1× resolution and then processed by the HiFi Digital Zoom system **400** into a digitally zoomed image blended imaging having a higher quality than an image produced from other digital zoom methods (e.g., single-frame interpolation algorithm and the iterative multi-frame interpolation methods described above).

FIG. **7** illustrates a process for custom tuning and control of camera firmware according to this disclosure. The embodiment of the process **700** shown in FIG. **7** is for illustration only. While the flow chart depicts a series of sequential steps, unless explicitly stated, no inference should be drawn from that sequence regarding specific order of performance, performance of steps or portions thereof serially rather than concurrently or in an overlapping manner, or performance of the steps depicted exclusively without the occurrence of intervening or intermediate steps. The process depicted in the example depicted is implemented by processing circuitry chain in, for example, a UE. The camera **200** implements the process **700** upon entering the HiFi mode.

In block **705**, the exposure, color, and focus are locked. More particularly, in HiFi mode, the camera application **555** configures the camera firmware **202** to perform auto-exposure lock, auto-focus lock, and auto-white/color balance lock (collectively called 3A lock) while the burst of images is captured (i.e., during the burst capture period **312**).

In block **710**, the camera **200** restores the ISP **212** and the sensor **208** to a no-zoom (i.e., 1× zoom ratio) scenario. That is, the camera captures images during the burst capture period and performs image processing on the burst of images **300** at the 1× no-zoom resolution.

In block **715**, the camera firmware **202** sets the ISP **210** parameters **224** to retain more texture and aliasing at the cost of single frame image quality. That is, the firmware **202** generates "tuning" parameters **224** that are more suitable for image texture retention. The camera firmware **202** enables the ISP **210** to perform reduced noise filtering, reduced pixel defect correction, and reduced interpolation aliasing cancellation. Each of the ISP processed images **228***a*-**228***e* may have a lower quality than if processed by the ISP **210** in non-HiFi mode, yet the aliasing retention causes the blended image **440** and composite image **250** produced by the HiFi Digital Zoom system **400** to have a higher quality than the image that would have been output from the ISP **210** in non-HiFi mode.

In block **720**, the camera captures a burst of images **300**. After the burst capture period **312**, the camera **200** returns to a non-HiFi default mode by releasing the 3A lock in block **725**.

FIG. **8** illustrates various places within an imaging processing architecture where the HiFi Digital Zoom system **400** and its associated algorithm could be implemented an example UE according to this disclosure. The UE image processing architecture **800** shown in FIG. **8** is for illustration only. While the flow chart depicts a series of sequential steps, unless explicitly stated, no inference should be drawn from that sequence regarding specific order of performance, performance of steps or portions thereof serially rather than concurrently or in an overlapping manner, or performance of the steps depicted exclusively without the occurrence of intervening or intermediate steps. The process depicted in the example depicted is implemented by processing circuitry chain in, for example, a UE. The UE **800** could be the same or similar to the UE **100**, and the components of the UE image processing architecture **800** could be the same or similar to the corresponding components of the UE **100**.

The camera firmware is configured to use either: (1) fully processed images for HiFi zoom, (2) partially processed images for HiFi zoom, or (3) un-processed raw images from the camera sensor **808** for multi-frame HiFi zoom. The camera firmware is configured to execute the High Fidelity Zoom (multi-stage blending algorithm) as either the last stage of the processing pipeline, the intermediate stage, or the first stage.

In certain embodiments, the camera firmware implements the multi-frame high fidelity zoom through a pre-capture of multiple frames in a buffer followed by post-processing of the algorithm in an "off-line" fashion. In other embodiments, the camera firmware implements the multi-frame high fidelity zoom through a live capture of multiple frames followed by on-the-fly processing of the multi-stage blending algorithm. The camera firmware implements the multi-stage blending algorithm partially or fully in hardware.

The UE image processing architecture **800** includes an image sensor **808** for capturing a burst of images, a raw pre-processing block **806**, a raw Bayer to full color conversation **810**, and a post processing block **820** for applying sharpness enhancement, noise filtering, and contrast enhancement. The raw pre-processing block **806** can include a noise reduction filter (for example, noise filter **406**) and a sharpness enhancement processes (such as, a pre-sharpener **408**). The raw pre-processing block **806** further implements a block level compensation, a vignetting correction, a defect correction, atone mapping, a dynamic range nonlinearity analysis, and so forth.

The UE image processing architecture **800** includes the raw pre-processing block **806**, such as the ISP **210**. The raw pre-processing block **806** implements demosaicing, gamma conversation, and color conversion. Also, the post processing block **820** implements sharpness enhancement, noise filtering and contrast enhancement.

The algorithm if the HiFi Digital Zoom system **400** can be implemented at location A, between the sensor **808** and the raw pre-processing **806**. Alternatively, the algorithm if the HiFi Digital Zoom system **400** can be implemented at location B, C, or D. Location B is between the raw pre-processing **806** and the raw Bayer to full color conversation **810**. Location C is between the raw Bayer to full color conversation **810** and the post processing **820**. Location D is after the post processing **820**.

Although the present disclosure has been described with an exemplary embodiment, various changes and modifications may be suggested to one skilled in the art. It is intended that the present disclosure encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A non-transitory computer readable medium embodying a computer program, the computer program comprising computer readable program code that, when executed by processing circuitry, causes the processing circuitry to:
- capture, by a digital camera, a burst of N images;
- for each image within the burst of images:
  - analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image,
  - generate an interpolated image by:
    - performing affine transformation using the set of affine matrices associated with the image,
    - applying an aliasing-retaining interpolation filter, and
    - implementing rotation transformation and sub-pixel shifts; and
  - blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

2. The non-transitory computer readable medium of claim **1**, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:
- automatically lock an auto-exposure, an auto-focus, and an auto-white/color balance of the digital camera while the burst of images is captured.

3. The non-transitory computer readable medium of claim **1**, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:
- generate and transmit a set of parameters to an image signal processor (ISP) of the digital camera, wherein the parameters are configured to cause the ISP to perform at least one of: reduced noise filtering, reduced pixel defect correction, and reduced interpolation aliasing cancellation.

4. The non-transitory computer readable medium of claim **1**, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:
- canceling aliasing by blending the N images into the single-blended image.

5. The non-transitory computer readable medium of claim **1**, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:
- sharpen the interpolated burst of images prior to blending the N images into the single-blended image.

6. The non-transitory computer readable medium of claim 1, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:

upscale the single-blended image by a remainder zoom ratio using a single-frame interpolation algorithm, wherein the remainder zoom ratio equals a user-selected zoom ratio divided by an upscaling zoom ratio to which the interpolated image is upscaled.

7. The non-transitory computer readable medium of claim 1, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:

select a reference frame from the burst of N images based on the reference frame having at least one of:

least motion difference from other images in the burst of N images,

a specified frame number,

a highest sharpness.

8. The non-transitory computer readable medium of claim 1, wherein the computer program further comprises computer readable program code that, when executed by the processing circuitry, causes the processing circuitry to:

receive the user-selected digital zoom ratio;

based on a determination that the user-selected digital zoom ratio is above a threshold value, upscale the burst of images using a high fidelity digital zoom;

based on a determination that the user-selected digital zoom ratio is above a threshold value, upscale the burst of images using a single-frame interpolation.

9. A mobile device comprising:

an embedded digital camera configured to capture a burst of N images;

processing circuitry comprising:

a registration module configured to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image;

a High Fidelity (HiFi) Interpolation block configured to, for each image within the burst of images: perform affine transformation using the set of affine matrices associated with the image, apply an aliasing-retaining interpolation filter, and implement rotation transformation and sub-pixel shifts, yielding an interpolated image; and

a blending module configured to receive the N interpolated images and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

10. The mobile device of claim 9, wherein the processing circuitry is configured to:

automatically lock an auto-exposure, an auto-focus, and an auto-white/color balance of the embedded digital camera while the burst of images is captured.

11. The mobile device of claim 9, wherein the processing circuitry is configured to:

generate and transmit a set of parameters to an image signal processor (ISP) of the embedded digital camera, where the parameters are configured to cause the ISP to perform at least one of: reduced noise filtering, reduced pixel defect correction, and reduced interpolation aliasing cancellation.

12. The mobile device of claim 9, wherein the blending module is configured to:

cancel aliasing by blending the N images into the single-blended image.

13. The mobile device of claim 9, wherein the processing circuitry is configured to:

sharpen the interpolated burst of images prior to blending the N images into the single-blended image.

14. The mobile device of claim 9, wherein the processing circuitry comprises:

second-frame interpolation block configured to upscale the single-blended image by a remainder zoom ratio using a single-frame interpolation algorithm, wherein the remainder zoom ratio equals a user-selected zoom ratio divided by an upscaling zoom ratio of the HiFi Interpolation block.

15. The mobile device of claim 9, wherein the processing circuitry further comprises:

a reference frame selection module configured to select a reference frame from the burst of N images based on the reference frame having at least one of:

least motion difference from other images in the burst of N images,

a specified frame number,

a highest sharpness.

16. The mobile device of claim 9, wherein the processing circuitry is further configured to:

receive the user-selected digital zoom ratio;

based on a determination that the user-selected digital zoom ratio is above a threshold value, upscale the burst of images using a high fidelity digital zoom;

based on a determination that the user-selected digital zoom ratio is above a threshold value, upscale the burst of images using a single-frame interpolation.

17. A system comprising:

processing circuitry configured to couple to a mobile device comprising an embedded digital camera configured to capture a burst of N images, the processing circuitry comprising:

a registration module configured to, for each image within the burst of images: analyze an amount of warp of the image and generate a set of affine matrices indicating the amount of warp of the image;

a High Fidelity (HiFi) Interpolation block configured to, for each image within the burst of images: perform affine transformation using the set of affine matrices associated with the image, apply an aliasing-retaining interpolation filter, and implement rotation transformation and sub-pixel shifts, yielding an interpolated image; and

a blending module configured to receive the N interpolated images and blend the N interpolated images into a single-blended image having a user-selected digital zoom ratio.

18. The system of claim 17, wherein the processing circuitry is configured to:

automatically lock an auto-exposure, an auto-focus, and an auto-white/color balance of the embedded digital camera while the burst of images is captured.

19. The system of claim 17, wherein the processing circuitry is configured to:

generate and transmit a set of parameters to an image signal processor (ISP) of the embedded digital camera, where the parameters are configured to cause the ISP to perform at least one of: reduced noise filtering, reduced pixel defect correction, and reduced interpolation aliasing cancellation.

20. The system of claim 17, wherein the blending module is configured to:

cancel aliasing by blending the N images into the single-blended image.

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